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Evaluation of Farmers Management Practices of Arabica Coffee Plantation Across Altitude for Climate Change Adaptation Strategies in Aceh, Indonesia

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Abstract – The productivity of Arabica coffee in low-altitude areas in Aceh have been declined, caused by an increase in temperatures, and by pests and diseases attack. This study aims to develop adaptation strategies to climate change in Aceh trough understanding how coffee productivity correlates with the management practices across the altitude. To find out a correlation between farming practices variables and coffee productivity, Spearman's rank test was used. To assess whether farming practice explanatory variables affected by the altitudes, a non-parametric with the Kruskal-Wallis Test, with Tukey's post-hoc test ($P<0.05$) with Chi-square distance were used. The results showed that coffee productivity was positively and significantly correlated to pruning, weeding, application of fertilizer, and application of pest and disease control, but was not to coffee plant density, sustainability certification, land conservation, and age of the coffee plant. Adaptation strategies for farmers in higher altitudes are to maintain the coffee plant density as well as shade density at an optimum level, followed by increasing management practices such as pruning, weeding, application of fertilizer, and pest and diseases control; in lower altitudes, those are to increase shade density both with Leucaena and multipurpose plants such as avocado and citrus, as well as increasing management practices such as land conservation, pruning, weeding, application of fertilizer and pest and diseases control. In middle altitudes, those are to maintain and improve management practices applied.

Keywords: Shade Trees, Coffee Productivity, Sustainability, Certification

Introduction

Coffee is one of the leading agriculture commodities for the people of Aceh, especially in the Gayo highlands, with production in 2018 reaching 58,422 t, from an area of 110,590 ha (BPS-Statistic Indonesia. 2019). Today, the productivity of Arabica coffee in Aceh have been declined, especially in low-altitude areas of 900-1200 m above sea level (a.s.l.). This condition is caused by an increase in temperatures and pests and diseases attack. Based on the A2 Climate Change Scenario, an increase in temperature of 2 oC is estimated to occur in 2050 (IPCC, 2000). Studies on the effect of global warming on coffee production, carbon, and energy footprint showed that coffee production was not only significantly decrease but also had a terrible impact (Hassard *et al.* 2014; Bunn *et al.*, 2015). In modeling studies, Schroth at al. (2015) reported that land suitable for coffee development in Indonesia by 2050 would be drastically reduced, even the coffee area in the Gayo highlands would reduce up to 91% compared to the currently suitable area.

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Rising temperatures and changing rain patterns resulted in decreasing coffee production (Magrach and Ghazoul, 2015; Bunn *et al*., 2015). The increase in temperature resulted in a condition that is more vulnerable to the production of Arabica coffee compared to the change in annual or sessional precipitation (Gay *et al*., 2006; Ovalle-Rivera *et al*., 2015). Sarmiento-Soler *et al*. (2020) showed that altitudinal gradient affected coffee yield components such as fruit load per branch, productive nodes per branch, and fruitful branches per stem at Mt. Elgon, Uganda, as well as on biochemical composition and quality of green arabica coffee (Worku *et al*., 2018). In another study, Cerda *et al*. (2017) showed that management practices affected coffee yield across altitudes in Costa Rica. This condition would cause farmers to look for land at a higher altitude. Unfortunately, this land is generally used for another agricultural product or is a protected forest area, which is very useful for maintaining ecosystem sustainability (Magrach and Ghazoul 2015; Schroth *et al*. 2015). This situation will threaten coffee and forest sustainability.

Arabica coffee is generally cultivated in agroforestry systems with Leucaena (*Leucaena leucocephala* (Lam.) De Wild) as shade trees. Farmers also grow other multipurpose plants such as avocado (*Persea americana*), citrus (*Citrus reticulata*), and banana (*Musa sp*.) between their coffee plants. Farmers in the Gayo region have begun to reduce existing shade trees to reduce competition with coffee plants in obtaining nutrients, space, and to increase the intensity of light received by coffee plants, to increase coffee production. Studies have shown that shade trees can reduce coffee yield (DaMatta, 2004; Vaast *et al*., 2006). Although, shade trees are useful for creating a microclimate, reducing the amount of fruit that falls (DaMatta, 2004; Vaast *et al*., 2006), reducing erosion, increasing plant nutrition (especially shade trees derived from legumes) (Cannavo *et al*., 2011; Sauvaded *et al*., 2019), as well as being food security (Tscharnke *et al*., 2011; de Souza *et al*., 2012).

As an area producing specialty coffee, the majority of farmers follow the guidelines of coffee sustainability certifications such as organic and fair trade. But in the implementation of the certificates, due to the limited labor and input for agriculture production availability such as organic fertilizers, pesticides, and herbicides, farmers reduce the intensity of land management. If the yield of coffee is low and cannot be compensated through a pattern of certification or premium prices, farmers will intensify their land management. In the short term, this will work, but in the long run, it will be at high risk due to negative consequences to the environment and ecology of the coffee-growing landscape (Barbar and Zak, 1995; Philpott *et al*., 2008).

To develop adaptation strategies for sustainable coffee production in Aceh, understanding how coffee productivity correlates with management practices across the altitudes, are essential, therefore we analyzed: the correlation between coffee productivity and management practices across the altitudes. We hypothesize that: i) coffee productivity does correlate to management practices across the altitudes, and ii) farmers at lower altitudes manage their farm better than those at higher altitudes.

Materials and Methods

Time and Sites

The study was conducted in 2019-2020 in two districts of major Arabica coffee producers in Gayo Highland, Aceh Tengah, and Bener Meriah. Aceh Tengah District located geographically between 4°22’14.42” – 4°42’40.8” N and 96°15’23.6” – 97°22’ 10.76” E, and Bener Meriah District located geographically between 4°33’50” – 4°54’50”N and 96°40’75” – 97°17’50”E (Figure 1). The mean annual rainfall (2009-2018) was 1,652 mm, with one peak in February–March and another in October–November. The mean annual temperature (2009-2018) in the study site was 20.94 °C, with a high variation between the daily and nightly temperatures (BMKG, 2019). The soil in the lower elevations was classified as Ultisols, while Inceptisols were found in higher elevations, and Andisols were found in the lower and higher elevations.

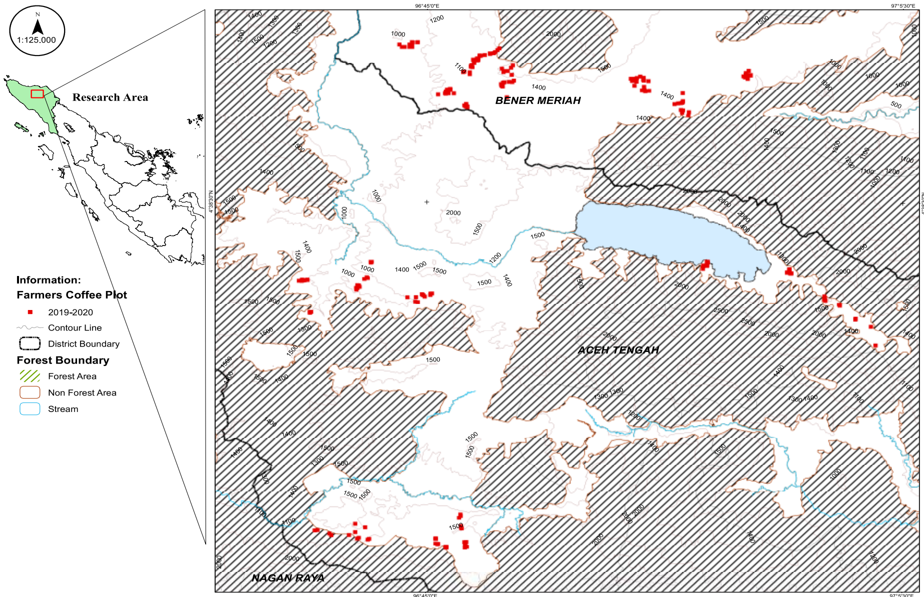

Figure 1. Research area (234 farmers' plots) in districts of Aceh Tengah and Bener Meriah

Data Collection

A mixed and stratified household survey was conducted with 234 farmers' plots. The survey was conducted using a face-to-face interview based on a structured questionnaire set. Pre-test and focus group discussions were conducted before the survey to finalize the survey instrument. The interviewers were trained by the same person, and surveys lasted between 45 and 60 min per farmer. The interviewers directly assessed the farmer's plot, recorded the altitude (using GPS), and counted density and type of shade trees, age of the coffee plants, plant spacing, and land conditions (flat or sloped).

We categorized our sampling along a 100 m altitude gradient, i.e. category 1 (1,000–1,100 m a.s.l.), category 2 (1,100–1,200 m a.s.l.), category 3 (1,200–1,300 m a.s.l.), category 4 (1,300–1,400 m a.s.l.), category 5 (1,400–1,500 m a.s.l.), and category 6 (1,500–1600 m a.s.l.). We examined farmers' plots consisting of 52, 26, 48, 36, 39, and 33 plots at category 1, category 2, category 3, category 4, category 5, and category 6, respectively. Farmer's plots were selected based on the criteria of having coffee with ages between 5 and 40 years, with a minimum coffee plant population of 300 plants/ha, and land ownership of at least 0.25 ha.

Management practices consist of coffee plant density, sustainability certification (no = 1, yes = 2), land conservation (sloped and no conservation = 1, flat or sloped with conservation = 2), age of the coffee (in years, where $5 \leq$ age < 10 y = 2; $10 \leq$ age < 25 y = 3, and ≥ 25 y = 1), pruning of coffee plants (no = 1, yes = 2), weeding (no = 1, yes = 2), applications of fertilizers (no = 1, applied organic or non-organic fertilizer = 2, applied both organic and non-organic fertilizers = 3), and application of pest and disease control (no = 1, yes = 2).

Coffee productivity (kg ha^{-1}) was calculated by dividing the yield of coffee reported by farmers for the 2019 harvest (January–December 2019) by the total area of farmer coffee plantation in the form of dry coffee beans, then converted to yield for one hectare of land.

Data Analysis

To find out A correlation between farming practices explanatory variables and coffee productivity, the Spearman's rank correlation was used. To assess whether farming practice explanatory variables affected by the altitudes, a non-parametric with the Kruskal-Wallis Test, with Tukey's post-hoc test ($P<0.05$) with Chi-square distance were used. Statistical analyses were performed with SAS ver. 23.0 (Licensed by IBM International).

Results

Farming Characteristics of Coffee Plantation

The average altitude of the farmers' plot was 1,282.39 ± 186.19 m a.s.l., with a minimum of 1,002 m a.s.l. and maximum 1,598 m a.s.l. The average farmer's land was 0.95 ± 0.52 ha. The majority of farmer's land ranged from 0.5 to 1.0 ha, but some farmers own land up to 3.0 ha. The average shade density was 146.90 ± 77.75 plants ha^{-1}, with Leucaena shade density at 127.23 ± 81.24 plants ha^{-1}, and avocado and citrus shade density were 19.80 ± 20.66 plant ha^{-1} (data is not shown). The average coffee productivity was 545.40 ± 161.98 kg ha^{-1}, ranging from 264.4 to 1,136.0 kg ha^{-1}.

The variety of coffee planted by farmers (data not shown) was Timtim (45.3%), Ateng Super (30.6%), mixed Gayo-2 and Ateng Super (7.7%), mixed Gayo-1 and Timtim (6.4%), mixed Borbor and Ateng Super (6.4%), Gayo-1 (3.8%) mixed Borbor and Timtim (3.8%), Gayo-2 (0.1%) and Bobor (0.1%).

Management practices carried out by farmers vary significantly from one to another. The average farmer who becomes a member of the sustainability certification was 1.31 ± 0.46—showing that only 43.7% of farmers joined sustainability certification, far from the claim that the majority of farmers were a member of sustainability certification. The average coffee plant density was 1,248.02 ± 460.13 plants ha^{-1}, ranging from 300 to 2,667 plants ha^{-1}. The implementation of land conservation was acceptable, with an average score of 1.6 ± 0.51. The average age of the coffee plant was in class 2, with an average of 2.5 ± 0.62 (15.1 ± 7.3 y). Pruning was generally done for production and had an average score of 1.5 ± 0.50. The average weeding score, application of fertilizer, and pest and disease control were 1.8 ± 0.36, 2.3 ± 0.82 of possibilities between 1.0 and 3.0, and 1.5 ± 0.50, respectively (Table 1).

Table 1. Farming characteristics of the coffee plantation (n=234 farmers plots)

Variable	Type of Variable	Mean (SD)	Min.	Max.	Corr.[1]
Coffee plant density (plant ha^{-1})	Continues	1,248.02 (460.13)	300	2,667	0.240ns
Sustainability certification	[yes = 2, no = 1]	1.31 (0.47)	1	2	-0.061ns
Land conservation	[Slope with no conservation = 1, flat or slope with conservation = 2]	1.63 (0.51)	1	2	-0.013ns
Age of coffee	[Age 5 - <10 y = 2. 10 -,25 = 3, and > 25 y =1]	2.48 (0.62)	1	3	0.100ns
Pruning	[yes = 2, no = 1]	1.53 (0.50)	1	2	0.645**
Weeding	[yes = 2, no = 1]	1.85 (0.36)	1	2	0.225**
Applications of fertilizers	[no =1, organic or non-organic = 2, both organic and non-organic = 3]	2.30 (0.82)	1	3	0.200**
Applications of pest and disease control	[yes = 2, no =1]	1.50 (0.50)	1	2	0.307**

SD = Standard deviation; [1]correlations between variables and coffee productivity were evaluated with the Spearman's rank correlation. ns=not significant, *=p<0.05, **p<0.01, and ***p<0.001.

Management Practices Across the Altitudes

Coffee plant density, sustainability certification, the age of the coffee, pruning, weeding, application of fertilizer and pest and disease control significantly differed across the altitudes; only land conservation did not significantly differ across the heights (Table 2).

Farmers at middle altitudes (from category 2 to category 5) planted more coffee plant density than those at type 1 and category 6. Pruning, weeding, application fertilizer, and application of pest and disease control were higher at middle altitudes (category 3-4) than those at higher altitudes (category 1-2) and lower altitudes (category 5-6). Farmer at middle altitudes (category 4-6) managed their coffee plantation more intensively than at lower altitudes and higher altitudes. Interestingly, fewer farmers at lower altitudes (category 1-3) followed sustainable certification than those at higher altitudes (category 4-6).

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Discussion

We reject our hypothesis that farmers in lower altitudes implemented higher management practices than in higher altitudes. Farmers in middle altitudes planted a higher density coffee than those in lower or higher altitudes. Lower coffee density corresponded with higher shade density, since Leucaena shade density and avocado and citrus shade density, though were not significantly different across the altitudes (data was not shown), were also higher in higher altitudes. These results could be due to differences in coffee plant spacing and reduction in shade trees. Rahn *et al.* (2018) reported that shade trees provided several ecosystem services as well as reduced risks at low altitude.

The hypothesis that increases in coffee plant density will be followed by higher management practices was in line with our findings in middle altitudes. These practices were also consistent with increases in their coffee productivity. Better yield at middle altitudes was related to lower temperatures than those at lower altitudes. Lower temperature protected coffee plants from severe damage caused by coffee berry borer (*Hypothenemus hampei*) (Avelino *et al.*, 2015; Aerts *et al.*, 2017). Therefore, the adaptation strategies in the middle altitudes are to maintain and improve current management practices. Considering that most farmers at middle altitudes follow sustainable certification, the application of organic input for fertilizer, pesticide, and herbicide would be a good choice to comply with their certification requirement.

Lower coffee productivity at higher altitudes with increasing in coffee plant density and shade density could be the result of lower management practices applied by farmers for their coffee plantation. Nevertheless, increasing coffee density can negatively influence the plants, as it reduces the available space and the incoming radiation below coffee canopies (Jassogne *et al.*, 2012). It would also increase nutrient demands on already exhausted soils (De Bauw *et al.*, 2016). Therefore, the adaptation strategy for farmers at higher altitudes is to maintain the coffee plant density as well as shade density at an optimum level, followed by increasing management practices such as pruning, weeding, application of fertilizer, and pest and diseases control. Considering that most farmers at higher altitudes also followed sustainable certification, the application of organic input for fertilizers, pesticides, and herbicides would be a good choice to comply with their certification requirement.

Coffee productivity at lower altitudes (category 1-2) was significantly lower than those at middle altitudes (category 3-4). This was due to higher temperatures in lower altitudes contrast to middle altitudes. This condition became worse with lower shade density and management practices than those at middle altitudes. Rahn *et al.* (2018) showed low coffee density as a factor causing low coffee yields in Uganda. Therefore, the adaptation strategies at lower altitudes (category 1-2) are to increase the number of shade trees both with Leucaena plants and with multipurpose plants such as avocado and citrus. An increase in shade plants will produce a microclimate that can reduce temperatures close to ideal conditions for growth, development, and yield of coffee.

Table 2. Farming characteristics and management practices of the coffee plantation at different altitudes

Variables	**Cat-1 (n=52)**	**Cat-2 (n=26)**	**Cat-3 (n=48)**	**Cat-4 (n=36)**	**Cat-5 (n=39)**	**Cat-6 (n=33)**	**Sig**[1]
	Mean (SD)						
Coffee plant density (plant ha^{-1})	1,104.1a (444.6)	1,472.3b (432.1)	1,398.8b (491.8)	1,293.5b (447.4)	1,262.8b (332.4)	1,011.6a (462.8)	***
Sustainability Certification	1.12a (0.32)	1.15a (0.37)	1.15a (0.36)	1.56b (0.50)	1.56b (0.50)	1.42b (0.50)	***
Land conservation	1.73 (0.45)	1.62 (0.50)	1.50 (0.55)	1.53 (0.56)	1.69 (0.52)	1.73 (0.45)	ns
Age of coffee	2.50 (0.61)	2.42 (0.64)	2.46 (0.74)	2.64 (0.49)	2.46 (0.68)	2.39 (0.50)	ns
Pruning	1.44ab (0.50)	1.31a (0.47)	1.79b (0.41)	1.61bc (0.49)	1.44ab (0.50)	1.48ab (0.51)	***
Weeding	1.77ab (0.43)	1.73a (0.45)	1.92c (0.28)	1.94c (0.23)	1.79abc (0.41)	1.91 bc (0.29)	*
Applications of fertilizer	2.63c (0.56)	2.38bc (0.64)	2.50c (0.74)	2.08ab (0.87)	1.72 a (0.97)	2.36 bc (0.78)	***
Applications of pest and disease control	1.36 a (0.49)	1.54 ab (0.51)	1.65 b (0.48)	1.61 b (0.49)	1.38 ab (0.49)	1.51 ab (0.51)	*

SD = Standard Deviation; [1]differences between variables and altitudes were evaluated with the Kruskal-Wallis test. ns=not significant, *=$p<0.05$, **=$p<0.01$, and ***=$p<0.001$; different letters in a row indicate mean differences within treatments (Tukey post-hoc test, $p< 0.05$)

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Shade trees have been specially recommended under sub-optimal environmental conditions (i.e., high temperatures, wind, or sloping terrain) due to their proven microclimatic regulation and soil protection function (Vaast *et al*., 2016; Sarmiento-Soler *et al*., 2019). Improving shading trees with multipurpose crops will also increase farmers' income (de Souza *et al*., 2011; Tscharntke *et al*., 2011); But, the activity should be followed by the increase of management practices to improve plant growth, development, and coffee yield, in terms of soil nutrition provision and adapt to local resource availability and do not harm the environment (Mbow *et al*., 2014). To reach sustainable coffee production, using organic agriculture inputs, and considering land carrying capacity are recommended.

Conclusion

Higher temperatures due to lower shade density as well as lower management practices in lower altitudes than those middle altitudes resulted in lower coffee productivity. The area can still produce coffee well if efforts are made to improve the microclimate by increasing the number of shade trees coupled with improved management practices.

Better management practices applied by farmers at middle altitudes than those at lower altitudes and higher altitudes resulted in better coffee productivity. The adaptation strategies in the middle altitudes (the area that will be affected by the increase in temperature) are to maintain and improve current management practices such as pruning, weeding, application of fertilizer and pest and diseases control.

Lower management practices as well as increase in coffee plant density and shade density applied by farmers at higher altitudes would lower coffee productivity. Therefore, the adaptation strategy for farmers at higher altitudes is to maintain the coffee plant density as well as shade density at an optimum level, followed by increasing management practices such as pruning, weeding, application of fertilizer and pest and diseases control.

Considering that most farmers at middle and higher altitudes also followed sustainable certification, the application of organic input for fertilizers, pesticides, and herbicides would be a good choice to comply with their certification requirement.

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